

# SCIENTIFIC INVESTIGATIONS INTO THE EUTROPHICATION OF THE NORFOLK BROADS

by

A W Davies

(Anglian Water Authority, Huntingdon)

## INTRODUCTION

The word "Broad" is used to describe a series of relatively shallow lakes resulting from the flooding of medieval peat diggings; forty-two broads have been recognised, varying in size from small pools to the largest of 120 ha. In the 1880's the total area of broads was approximately 1200 ha but this has been reduced to about 700 ha, due largely to marginal overgrowth of vegetation.

The broads are part of an extensive system of fens, marshes and interconnecting waterways in the catchment of the Rivers Bure, Yare and Waveney; this system is known as Broadland.

Broadland is essentially freshwater, but because the rivers have such low gradients the lower reaches are brackish. The influence of tide is particularly apparent on the River Yare; in Norwich 40 km from the sea there is a vertical movement of half a metre at spring tide. Hickling Broad and Horsey Mere and other waterways associated with the River Thurne, a tributary of the River Bure, are brackish, not as the result of tidal excursion but because a saline water table underlies this part of Broadland.

Considerable reclamation of the highly fertile alluvial land of Broadland has occurred over the centuries. Of the 23,500 ha in Broadland 20,500 ha have been embanked and partially drained for grazing and arable cultivation. The remaining 3,000 ha of unreclaimed fen provides some storage of floodwater impounded as a result of North Sea surges and high tides. These 'washes' are also utilised for reed and sedge crops.

The majority of the broads are located in the northern part of Broadland. There are few broads or unreclaimed fen within the valleys of the Rivers Yare and Waveney.

## USES OF BROADLAND

"The Broads" is one of Britain's best known holiday areas; it is also nationally and internationally recognised as a very important wildlife reserve.

### Tourism and Recreation

Broadland possesses 200 km of navigable waterways used by approximately 2,000 motor cruisers in 1974. In this year no less than 7,500 private vessels were registered on these waters. Estimates indicate that 200,000 persons enjoyed holidays afloat in 1975, while 100,000 sightseers used water buses. Only 16 broads are used for public navigation possessing a total water surface of about 400 ha. Most boating activity is in northern broadland. These activities result in erosion of river banks and subsequent silting of navigation channels, which require regular dredging. A significant increase in water turbidity levels has occurred in recent years which has contributed to a loss of vascular water plants (macrophytes) and, it has been suggested, to a decline in fisheries in certain waters.

## Agriculture

It has been estimated that 85% of the catchment of Broadland rivers is utilised for farming, mainly arable. Most of this land has been reclaimed by drainage operations which often require the construction of drainage dykes and pumping stations.

The change from grassland to arable farming and the application of fertilisers to this land, a proportion of which are lost to the drainage entering the Broadland, are contributory factors to the increasing eutrophication problem of the Broadland waters.

## THE PROBLEMS OF BROADLAND

The problems are basically the progressive loss of aquatic plants, in particular the macrophytes, animal life, outbreaks of avian botulism, occasional fish kills due to a toxin produced by the blue-green alga *Prymnesium parvum* and the emergence of very heavy algal blooms. To this is added the considerable reduction of marginal reed swamp, perhaps in part due to 'boat' erosions and dredging, resulting in the loss of important habitats of many waterfowl. However, the precise mechanism of reed swamp "die-back" is still the subject of research. Since the loss of the marginal reeds (*Phragmites*) which stabilised the river banks, permanent flooding of some important unreclaimed 'wetlands' has occurred.

There are a number of factors thought to be responsible for the deterioration of the Broadlands, the two most significant being:—

- a. Eutrophication resulting from enhanced nutrient inputs, in particular of nitrates and phosphates, from a variety of sources. The most important of these are sewage effluents, agricultural drainage, which includes fertilisers and nutrient rich effluents from piggeries and dairy units. Roosting gulls on the Broads, the release of nutrient from the sediment and the increasing nitrogen oxides dissolved in raw water from fossil fuel combustion are also thought to make a measurable contribution to the enrichment of the water.
- b. navigation has almost certainly assisted in accelerating the changes in Broadland by causing erosion of banks, and increasing turbidity, siltation and flooding.

It is apparent that the problems of the Broadlands do not derive from a single causative factor but result from an additive process of a large number of variable factors. The ways in which these may be related one with another to produce an observable effect has been summarised in Figure 1. by M George\*. No apology is given for the apparent complexity of this presentation, as it is confidently assumed that it is an over-simplification of the "Broadland complex". To attempt to resolve the primary causes for the Broadland problem a considerable amount of research has and is being undertaken; the more important projects are briefly described in the next section of this paper.

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\*George, M. The Decline in Broadland's Aquatic Fauna and Flora:  
A Review of the Present Position.  
Transactions of the Norfolk and Norwich Naturalists Society, 24, part 2  
(April 1977).





## RESEARCH IN BROADLAND

### Water Quality, Nutrient Budgets and Basic Limnology

The Broadlands being investigated at present include Barton Broad, Hoveton Great Broad, Hickling and Brundall Broad, Breydon Water and Alderfen Broad.

**Barton Broad** — This Broad is highly eutrophicated; one of the major contributory factors is thought to be the phosphorus in sewage effluents discharged from the Stalham Sewage Treatment Works. Since April 1978 some 90% of the soluble reactive phosphorus has been removed from the effluent by precipitation. It is hoped that after two to three years, macrophytes will become re-established in this Broad. Sediment-release of phosphorus is also being investigated from the mud deposits.

**Hoveton Great Broad** — The research is to assess the effectiveness of partially closing Hoveton Great Broad; a lake renewal technique.

There is little detailed information on the existing limnology, hydrometry and ecology of the highly enriched Hoveton Great Broad. Base line data on water chemistry, water movements and aquatic biota will be collected prior to its partial closure from the River Bure. Sampling stations will also be established on the River Bure, and in Wroxham Broad for control purposes. Monitoring will continue after closure and data compared with events prior to closure and with data from the control stations. In addition sedimentation rates and the post-medieval history of the broad will be established using diatom remains and radio-isotope dating techniques.

**Hickling Broad** — Since 1969 macrophyte communities have been rapidly replaced by phytoplankton. The objective of the investigation is to determine the extent to which nutrient loadings, and surface instability and boating activities are responsible.

The project involves the separation of two water columns using "Lund Tubes", 20 metres in diameter. These tubes are suspended from buoyant collars and anchored on the bed. As the water column is isolated from the chemical quality of the surrounding water, the effects of various factors can be assessed separately.

So far the very high inorganic dissolved phosphorus concentration in Hickling Broad can only be explained from a very high black-headed gull population, in excess of 100,000, which roost in winter on this Broad.

It has been shown, using these tubes, that the effects of boats which increase the instability of the mud is of secondary importance to the enrichment problem.

**Brundall Broad** — In this experiment the Brundall inner broad has been isolated from the River Yare by a dam and events compared with the adjacent outer broad which remains open to the river. The River Yare is the most highly enriched in Broadland, in part due to the effects of a large sewage effluent discharge.

Results to date (1976-79) indicate that the inner broad has become clear and is now supporting a good growth of macrophytes.

**Breydon Water** — Work on this broad is now completed. The inputs and outputs of phosphorus to Breydon have been measured and the relationships of the sediment and water in phosphorus exchange have been analysed. Breydon sediment is stirred twice daily by tides and receives large amounts of phosphate from the Broadland rivers. The sediment acts as a net sink for phosphorus and its phosphorus absorbing capacity is utilised at only one eightieth of its potential.

**Alderfen Broad** — The objective of this research is to determine if the seasonal diversion of nutrient enriched water will enable the re-establishment of aquatic macrophytes.

Although Alderfen Broad is isolated from the influence of the highly enriched River Ant, aquatic macrophytes and their associated invertebrate fauna died out during the late 1960s. Research workers from the University of East Anglia (UEA) have concluded that macrophyte loss can be directly attributed to eutrophication. Two sources have been identified, i. septic tank outfalls and live-stock slurry from an adjacent hamlet providing phosphates, ii. leached farm fertilisers from the catchment providing nitrogen salts.

The bulk of these nutrients enter the broad during the period November to February and are available in sufficient quantity to initiate a Winter/Spring phytoplankton bloom. Although nutrient inputs decline after Winter flushing to reach very low levels by the end of March, the broad is able to sustain phytoplankton growth throughout the Summer. From the data available it is believed that sufficient  $\text{PO}_4$  and  $\text{NH}_4$  are released from the sediments when conditions of chemical reduction arise at the sediment surface, a situation, which is met following the death and decay of the winter/spring phytoplankton crop. The highly turbid water, prevents the successful establishment and growth of macrophytes.

It has been suggested by UEA research workers that the re-establishment of macrophytes can only be achieved if the recycling process is broken and they have suggested that this could be done by diverting during the Winter months the inflow stream away from the broad which carries the excess nutrient load.

More general investigations in Broadlands are being undertaken on water quality and nutrient balances; the more important are briefly described below:—

**River Thurne** — Much of the Thurne catchment is subject to saline intrusion, values of 3,500 mg/l chloride being measured in Horsey Mere and the Thurne system. The high salinity adversely affects agriculture and the ecology of the area and is known to be associated with the *Prymnesium* algae and fish mortalities.

It is proposed (1979–1982) to investigate the source of salinity by the construction of observation boreholes to ascertain the groundwater movement and extent and concentration of saline groundwater. Up to 3 boreholes 50m deep and 10 shallow boreholes will be required.

#### **Water Quality and Biological Monitoring Programme**

The Anglian Water Authority has undertaken to substantially increase its sampling of waters in Broadland for biological and chemical quality assessment (1979–81). This additional work is designed to complement and assist all the other research projects being undertaken throughout Broadland. Many quality factors will be measured including ammoniacal nitrogen, nitrites, nitrates, dissolved and total phosphorus; reactive silica, chlorides, iron, detergent, dissolved oxygen, turbidity, pH, chlorophyll, algal counts, light absorption and zooplankton.

## **Prymnesium parvum in Broadland**

Since the early 1970s an investigation into the population dynamics of the alga *Prymnesium*, toxin production and water quality has been undertaken. The population size is related to nutrient loading in the various parts of the Thurne (Martham Broad versus Horsey, Hickling, Heigham Sound versus Womack Water). Cultures have been established and compared with Israeli cultures. There are some genetically determined differences in growth rate, salinity tolerance and toxicity. Available evidence indicates that the recent series of toxin induced fish kills at Hickling Broad and Horsey Mere are related to enrichment of these waters and not, as previously thought, to increased salinity. Toxin is released on cell lysis following a period of nitrogen stressed growth. Nitrogen limitation occurs at both Hickling and Horsey during the Summer as algal crops build up, and under these conditions *Prymnesium*, which is unable to compete successfully with other phytoplankters, dies. This contrasts to the situation in Womack Water which is directly influenced by the effluent from the nearby Ludham Sewage Treatment Works. Here *Prymnesium* is able to sustain large crops as the water remains consistently fertile.

## **Nutrient Budget for the Broadlands System**

A synoptic survey has shown that the major cause of turbidity in the entire system is due to dense populations of phytoplankton. Natural water movement (wind and tidal) causes a minor background turbidity, and boat disturbance an even smaller amount.

Sufficient is now known of the Broadland catchments to apply recently developed mathematical models to predict effective phosphate levels in the water from agricultural information, human population sizes and meteorological and hydrological parameters. These calculations are being continually refined, but indicate that natural and agricultural inputs over the system as a whole are insufficient to have caused the turbidity problem and loss of macrophytes. All indications are that, except in the Thurne system, levels from sewage effluent, building up annual loadings since the early decades of this century, have reached levels in the past two decades which have caused a rapid decline in macrophytes.

## **Hydrographic and Hydrometric Studies**

These studies are longterm, in excess of ten years, and are designed to provide a data base for water-related research.

The parameters which will be extensively measured are rainfall, riverflows, tide levels and conductivity. For the most part the instrumentation is by continuous measurement, results are chart recorded. Work commenced in 1977 on twenty-eight key river sections established to measure rates of erosion and deposition throughout the Broadlands complex. The problem is that river banks in many areas are subject to erosion, in part due to boating activities. It is uncertain how much of the eroded material is carried out of the system and how much is deposited locally on the river bed.

There may also be more fundamental and far reaching processes at work. Port depths at Great Yarmouth have been progressively increased by improved dredging techniques and harbour construction works over the four centuries since the entrance was stabilised at its present position, and there are some indications that lower tidal reaches of the Broad rivers have not yet reached a state of equilibrium and may be increasing both in width and depth in response to these works and the longterm increase of mean sea level relative to land level on the East Coast.

## Biological Investigations

This section briefly considers if the introduction of macrophytes into a eutrophicated water can allow them to be re-established and why macrophytes decline. Surveys of Broadland rivers to quantify phytoplankton, zooplankton, benthic invertebrates and macrophytes are being undertaken. A study of aquatic flora and fauna in Broadlands' grazing marsh dykes, and the lower reaches of the Yare and Bure rivers has been carried out. Avian botulism is also a problem causing the deaths of many hundreds of water fowl. Fish population studies to provide quantitative data are being undertaken; evidence suggests a decline in fish stocks in certain waters over recent years. Various investigations are also being conducted to predict occurrence of *Prymnesium*, into the movement of fish during ichthyotoxin release and the possible use of ammonia to prevent the build-up of *Prymnesium* populations.

### Re-introduction of Macrophytes — Barton Broad

This project is intended to complement the Anglian Water Authority nutrient monitoring programme which has commenced, following the provision of phosphate-removal plant at Stalham Sewage Treatment Works. It is expected that total phosphorus levels will be lowered sufficiently to permit growth of submerged aquatic macrophytes, but it has not been established whether sufficient propagules remain in the Broad, or whether protection will be needed from mechanical damage by boats, in the early stages of recolonisation.

### Grazing Marsh Dykes Investigations

A detailed survey recently completed has confirmed that the most important remaining refuge for aquatic plants and invertebrates left in Broadland is the extensive system of dykes associated with the 20,250 ha of reclaimed marshland. Parts of this system have been adversely affected by eutrophication, by saline water infiltration and by unsympathetic forms of management, but other areas still possess a remarkably rich diversity of aquatic species including national rarities such as Sharp-leaved Pondweed (*Potamogeton acutifolius*) and the dragonfly *Aeshna isosceles*. The survival of this fauna and flora can be attributed firstly to the fact that unlike the fenland waterways further to the west, aquatic herbicides have not displaced mechanical methods of dyke management, and secondly, that since most of the marshes are still used for pasturage, the majority of the dykes are kept fairly full of water in order to prevent cattle straying from one place to another.

Agricultural improvement, involving the conversion of the marshland to arable, and the subsequent cropping of the land for cereals, root crops or grass for silage usually involves the lowering of the water levels in the dykes. It has been shown that this is soon followed by the impoverishment of their aquatic fauna and flora; this is caused partly by the more frequent cleaning out of the dykes, and partly by the remaining water which the latter receives from the adjoining land. Salinities in some dykes also tend to rise as a result of the leakage of brackish water through the flood banks of the rivers.

### Avian Botulism

This is a paralytic disease of birds and mammals, caused by the ingestion of a neurotoxin produced by the anaerobic bacterium, *Clostridium botulinum*, whose natural habitat is mud and soil. Outbreaks of type C, or avian botulism, are characteristically associated with long periods of warm sunny weather, and the presence of extensive areas of shallow, stagnant water in which oxygen levels have been depleted by accumulations of rotting vegetation and other organic matter. Habitat conditions in Broadland are now well suited to the bacterium and outbreaks of botulism in waterfowl have occurred every year since 1969, with the exception of 1972. Over a thousand birds were killed during the Summers of 1975 and 1976.



The completed research included investigations into the microflora and physico-chemical properties of Broadland mud samples, to determine to what extent these differ from muds from similar, but non-infected sites. It is believed that the species composition of the mud micro-flora becomes impoverished under eutrophic conditions and that these conditions confer a competitive advantage on the anaerobic *Clostridium botulinum*. This hypothesis has been tested by laboratory and field trials and it is expected that this work will lead to a greater understanding of the interactions between components of the mud micro-flora, thus enabling remedial measures to be taken.

#### **Factors Responsible for the Dieback of Marginal Reedswamp**

The initial phase of this research is now completed. The objective was to determine the rate and extent of reedswamp regression at different sites in Broadland and to investigate what factors may be responsible for the observed changes.

The performance of reedswamp is affected not only by edaphic factors like water regime, temperature and light, but by biotic influences such as grazing by coypus, swans and geese, trampling and by the mechanical damage caused by boats being driven into or moored alongside the marginal vegetation. Elsewhere the reedswamp has disappeared, or become impoverished for no obvious reason, for example, Ranworth Broad is largely devoid of reedswamp even though public boating is prohibited. It is tempting to relate this to the effects of eutrophication, but as yet no hard evidence for this hypothesis exists. Analysis of aerial photographs has thrown light on the rate at which reedswamp has been lost from the Bure Broad. In addition, the study has shown that the loss of reedswamp can be correlated with the presence of deep accumulations of organic muds in the broads.

#### **Fish Population Studies**

The objectives of this study are:-

- a. to develop methods for surveying fish populations in Broadlands and Broadland rivers.
- b. to use these methods, to obtain background information on the fish population in different parts of Broadland. (Includes assessment of species composition, year class growth rates, estimates of abundance and other information relevant to the future management of fish stocks for angling).
- c. To investigate, by tagging, the movements of pike in Broadland waters.

The angling fraternity are confident that there has been, over the past few years, a noticeable decline in fish catches in some waters. It is with this observation in mind and also the need to assess fish populations for the enhancement of fisheries management that this work is being undertaken.

#### **Historical Research**

Research on core samples taken from Barton Broad on the history of sedimentation and the nutrient budgets in the Broad over the past 180 years has been largely completed. Sedimentation rates using diatom remains and radio-isotope dating techniques are also being applied to a large number of broads dating to at least the past one hundred years.

Searches of the literature and the compilation of a bibliography to assess and interpret visual changes during at least the last 35 years have been concluded.

### **Summary and Conclusions**

It is apparent that the deterioration of the Broadland ecology cannot be attributed to any one single factor; it is a very complex interrelationship of a large number of factors, many of which are difficult to quantify. What is certain is that during the past ten years considerable changes have occurred which are thought by the majority to be unacceptable. These judgements are not only based on aesthetic considerations but much evidence exists of a considerable loss of plant and animal diversity.

This paper describes only a part of the research effort which has been applied to better understand the causative factors responsible for the Broadland decline. Once these have been adequately quantified the next step will be to decide what action is required, to reverse the deterioration. It is anticipated that such action will require to be on a massive scale accompanied by an equally large expenditure. Whenever money is spent without apparent material return the argument for its expenditure requires to be extremely persuasive. In the 'field' of conservation the cost-benefit yardstick is almost unquantifiable, as what is environmentally acceptable to one will be anathema to another. The assessment of the quality of life, which includes the natural and synthetic environments is as variable as the individual. From this it is concluded that perhaps the most difficult problem in Broadland is not to define the causes for its decline but to raise enough money to reverse the processes and having done so to maintain control over them.

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